Numerical Modelling of Molding Compression Of Fibre-Reinforced Composites for Industrial applications

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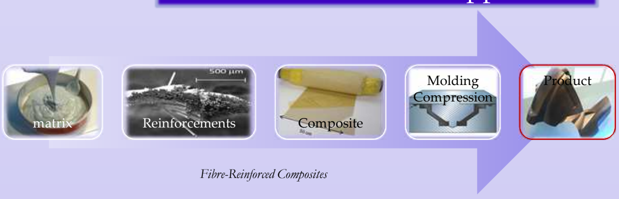
Abstract

A transverse isotropic viscous model accounting for the anisotropy exhibited in fiber-reinforced composites is integrated in the numerical platform of the software Rem3D®. Simulations under various mechanical loadings are tested for volume fiber concentrations of 3.5% and 14.7%. Equivalent stresses and equivalent strain rate deformations given by the software were compared to the ones coming from experimental data, finding very good agreements. As a second point developed on this paper, we comment on the slip condition between Die/Punch tool with the composite under compression. We noticed that the variation of the viscosity value on a small layer between the Die/Punch tool and the composite affects the nature of the contact. A viscous friction is then formulated as a technique to set slip/no-slip contact conditions. We found that the slip condition is recovered at lower values of the viscosity in the interface Die/Punch with the reinforced composite, whereas the no slip condition stated for higher viscosity values.

Process and Industrial Application



Fibre-Reinforced Composites

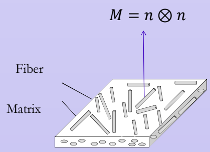
high performance and low density

Automotive: 10% weight reduction compared to all-aluminium design

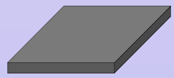
Renewable Energy components

Rheological Behaviour of SMC under Compression

$M = n \otimes n$



Composites with anisotropic properties



Homogenisation

Fiber and Matrix are seen as a single phase

Fiber Orientation $\perp n$

Variables depending on the fiber fraction

$D = \dot{\varepsilon}$

Strain rate deformation

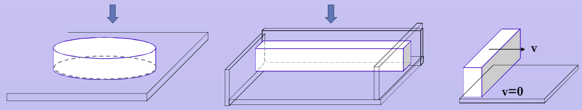
Rheology Model

To account for the anisotropy exhibited in reinforced composite

$$\sigma = \alpha_0 K^f D_{eq}^{m-1}\left[D + \alpha_1 (M:D)M + \frac{\alpha_2}{2}(D\cdot M + M\cdot D)\right]$$

$$D_{eq}^2 = \alpha_0[D:D + \alpha_1 (M:D)^2 + \alpha_2 (D\cdot M:D)]$$

Test Cases

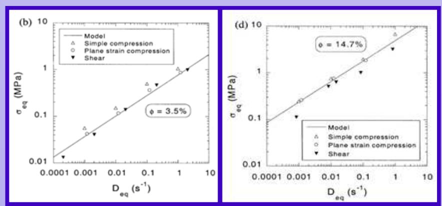


Simple Compression — Plane strain compression — Shear

Three cases has been set to validate our numerical integration in Rem3D. Simple compression, plane strain compression ans shear were the test used to obtain the rheology model [Dumont,2003]. In here; we repet such tests and validate – verified with experimental results.

Comparison Model with Experiences [Dumont et al. 2003]

Experiences



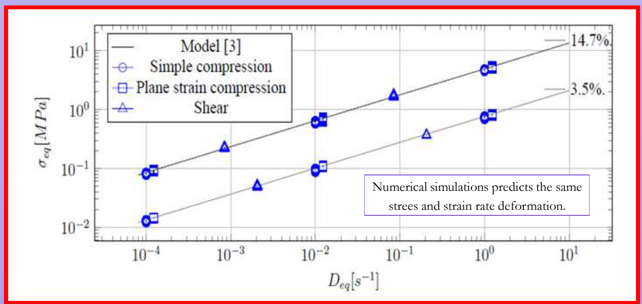
Experiences and model have really good agreements.

a) For Fiber volume fraction of 3,5%

b) For Fiber Volume fraction of 14,7%

Comparison Model with Numerical Simulations [Salazar et al. 2015]

Simulations



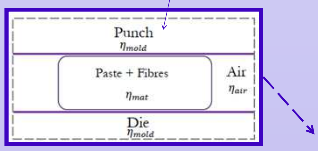
Immersed Method

[Coupez et al. 2010]

The different materials are represented by a single mixture equation

$$\rho(x) = H(x).\rho_1 + (1 - H(x)).\rho_2$$
$$\eta(x) = H(x).\eta_1 + (1 - H(x)).\eta_2$$

Mixture Law



FEM Resolution $\rho(x)(\partial v_t + v\nabla v) - \nabla\cdot\sigma = \rho(x)g$

$\nabla \cdot v = 0$

Level Set Method

Signed Distance

$$L_s = \bar{d}(x,\Gamma) = \begin{cases} d(x,\Gamma) \text{ if } x \in \Omega \\ -d(x,\Gamma) \text{ if } x \notin \Omega \end{cases}$$

Narrow Level Set — Heaviside Function

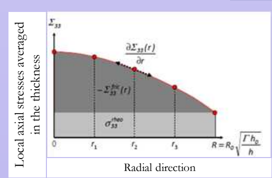
$$\chi = E \tanh\left(\frac{L_s}{E}\right) \qquad H(\chi) = \frac{1}{2}\left(1 + \left(\frac{\chi}{E}\right)\right)$$

Transport of Level Set

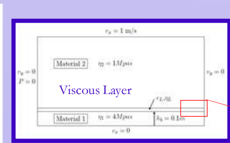
$$\frac{\partial \chi}{\partial t} + (v + v_r)\cdot\nabla\chi = f(\chi),$$

By solving the multiphase FE resolution, we obtain the solution of each domain

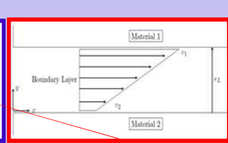
Friction Modeling



The normal stress depends on the size of the specimens, due to friction effect



Simple Shear test performed on 2x1(m)



Viscous friction approach

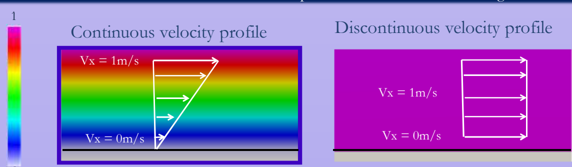
Friction Law $\tau = \alpha\, v_\tau$

coefficient relation $\alpha = \frac{\eta_L}{e_L}$

In our immersed domain, we insert a layer asigned with a thickness and a viscosity. These two factors enable the setting of a friction coefficient.

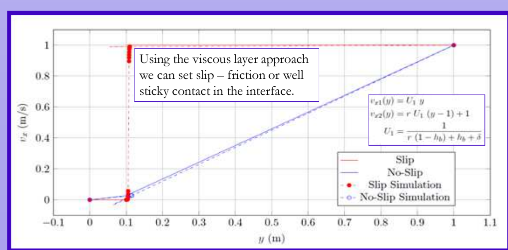
Numerical difficulty: obtaing a discontinuous velocity profile in an immersed volume method with mesh adaptation and automatic remeshing

Continuous velocity profile — Discontinuous velocity profile



No-slip contact is given for high values of alpha — Slip contact is given for low values of alpha

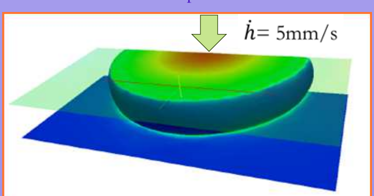
Simulations And Theory



Compression with friction

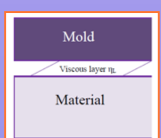
- Compression of fiber material with 14,7% weight fiber concentration.
- Friction coefficient has been set. $e_L = 2.10^{-4}$

Compression



Numerical Resolution: Rheological Model for Reinforced Fibre composites is used to described the mechanics

Viscous Layer is used to set the lubrication condition in the interface Mold/Composite



- Conservative equations

$$\begin{cases} \nabla\cdot(2\,\eta_k D(v^{t+1}) + \sigma_s(v^{t+1})) - \nabla p^{t+1} = 0 \\ \nabla\cdot v^{t+1} \\ +B.C \end{cases}$$

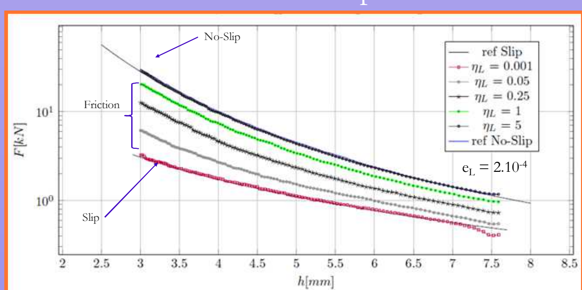
$=> (v^{t+1}, p^{t+1}) -> \eta_{k+1}$

- Transport Equation

$$\frac{\partial \chi^{t+1}}{\partial t} + (v^{t+1} + v_r^{t+1})\cdot\nabla\chi^{t+1} = f(\chi^t)$$

$=> (\chi^{t+1})$

Friction effect on the compression force



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